PLANKTON INVESTIGATION IN INLET WATERS ALONG THE COAST OF JAPAN

XI. THE PLANKTON OF KOZIMA BAY IN THE SETO-NAIKAI (INLAND SEA)[1]

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With 33 Text-figures

The muddy flat within the western-most areas of Kozima Bay, Okayama Prefecture, covering the extensive delta areas of the two rivers, the Sasagase and Kurasiki, is now reclaiming in order to reform there as paddy fields under the governmental management. Recently the damming work to keep freshwater for irrigation inside is now in progress between the village of Kori and the Okayama Harbour and scheduled to be completed before long. Since the early summer of 1951 a detailed survey was begun of the plankton and bottom fauna of the sea area concerned under the direction of Prof. D. MIYADI of Kyoto University. The principal aim of investigation was to obtain an accurate picture of biological conditions on the grounds to form a basis for an assessment of the changes which occur when such grounds are reclaimed and restored to an agriculturally productive condition. This survey shall be repeated in the coming five years till the damming work will be accomplished.

The present paper deals only with the seasonal changes of the hydrological and planktological conditions in the eastern main area of the bay still to be remained as bay conditions, which has been elucidated by myself took a part of this investigation. As to the problem of succession of the planktonic and benthic fauna and flora within the dammed area which may be expected to result from the reclamation, another interim report now in preparation will be devoted.

During this survey the plankton was hauled at each station from the 3 meter layer to the surface and from the bottom to the 3 meter layer by a KITAHARA's quantitative silk tow net in a small scale, equipping with no. XX-13 MÜLLER's gauze. The diameter of the mouth and largest part of the net are 11.25 cm and 25 cm respectively

1) Contributions from the Seto Marine Biological Laboratory, No. 229.

and the length about 50 cm. Therefore, the net passes through the water of approximately 10 liters in every towing for one meter length. General methods of examination are the same as those mentioned in my previous papers of this series. All plankton figures and data imply the volume or number per one meter haul.

Thanks are due to Mr. S. TOKUNO, Director of the Kozima-wan Reclamation and Construction Branch Office of the Ministry of Agriculture and Forestry, and staff members. Prof. S. KAWAGUTI, Mr. K. MATSUMOTO and other members of Okayama University and also Messrs. T. HABE, Y. KUSAKA, H. MAÉDA and S. FUSE of Kyoto University were kind enough to help and cooperate in various ways of this investigation. To all these gentlemen's cooperation I wish to extend here my heartfelt gratitude.

Hydrological Conditions

Kozima Bay is a small bay having an estuarine character situated on the northern coast of the Seto-Naikai (Inland Sea) near Okayama City (Fig. 1). It is about 15 km

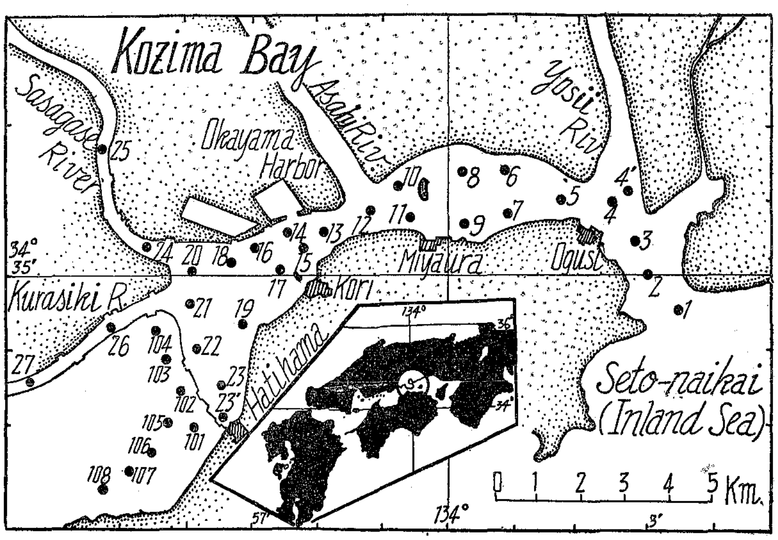


Fig. 1. Chart of Kozima Bay showing stations.

long in the E-W direction and narrowed in the N-S direction. The bay is very shallow, mostly from 3 to 8 m deep (Fig. 2, A). The mouth towards the estuary of Yosii River is a little shallower than the middle region, which forms a lengthwise trench at the depth, about 10-15 m deep. The northern part of the middle region is very shallow less than 2 m in depth, where lies a small islet of Takasima. The inner coastal region is, however, a little deeper, being about 2.5-5 m deep. The bottom

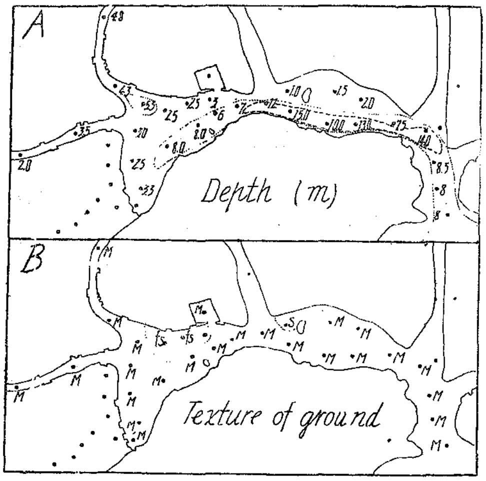


Fig. 2. Map showing bathymetric contours (A), and texture of ground (B). *M*-mud, *S*-sand, *fs*-fine sand.

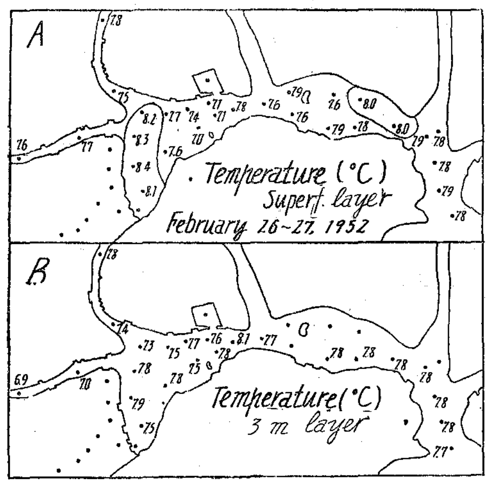


Fig. 3. Distribution of water temperature (°C) during February 26–27, 1952.

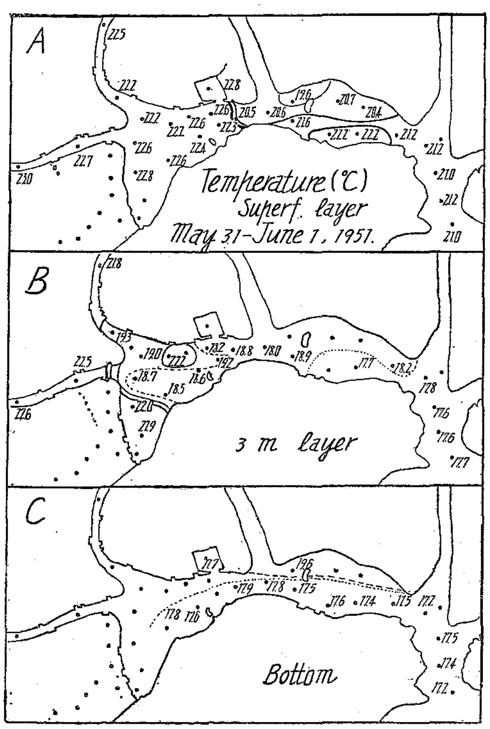


Fig. 4. Distribution of water temperature (°C) during May 31–June 1, 1951.

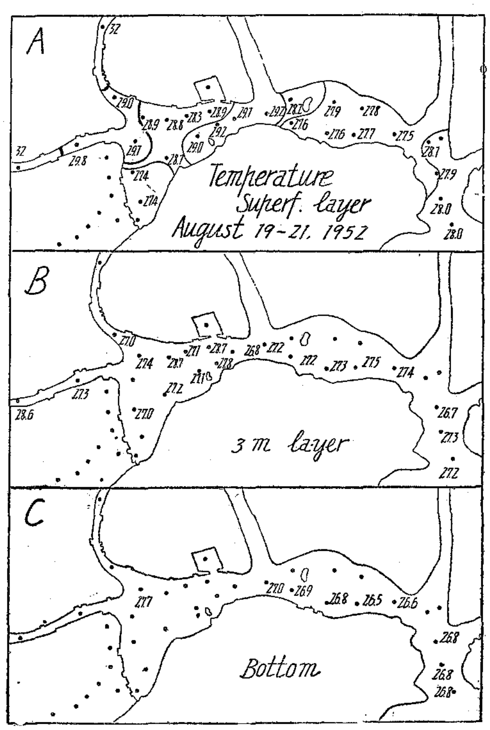
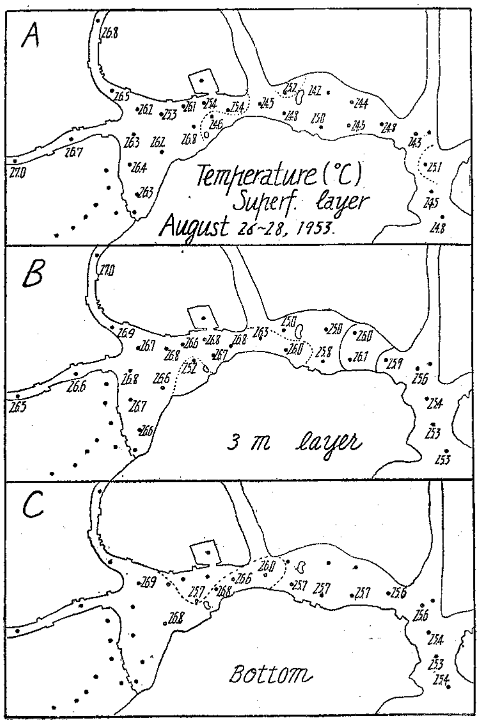


Fig. 5. Distribution of water temperature (°C) during August 19–21, 1952.



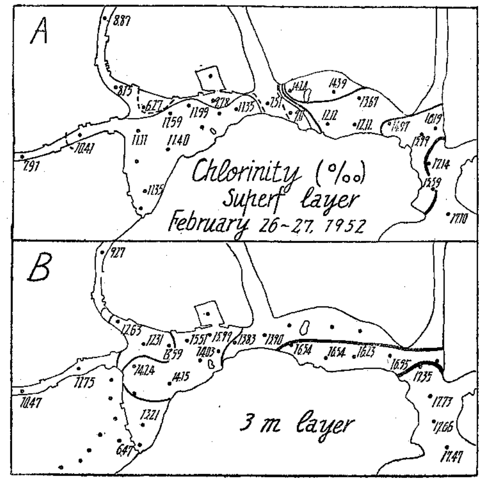


Fig. 7. Distribution of chlorinity in ‰ during February 26–27, 1952. (Above)

Fig. 6. Distribution of water temperature (°C) during August 26–28, 1953. (Left)

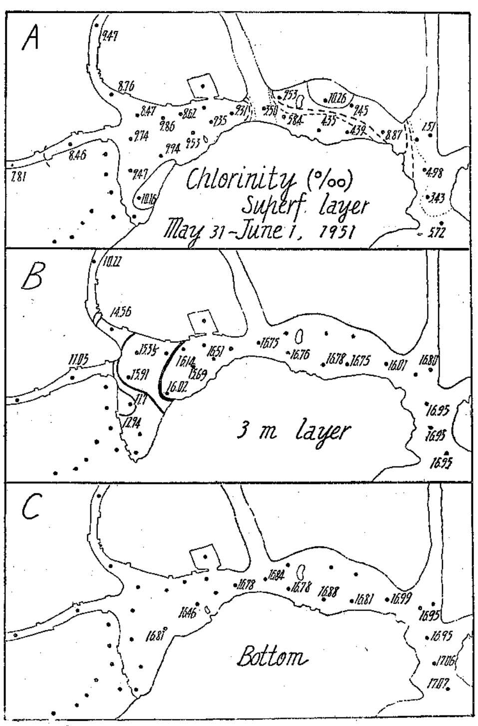


Fig. 8. Distribution of chlorinity in ‰ during May 31–June 1, 1951.

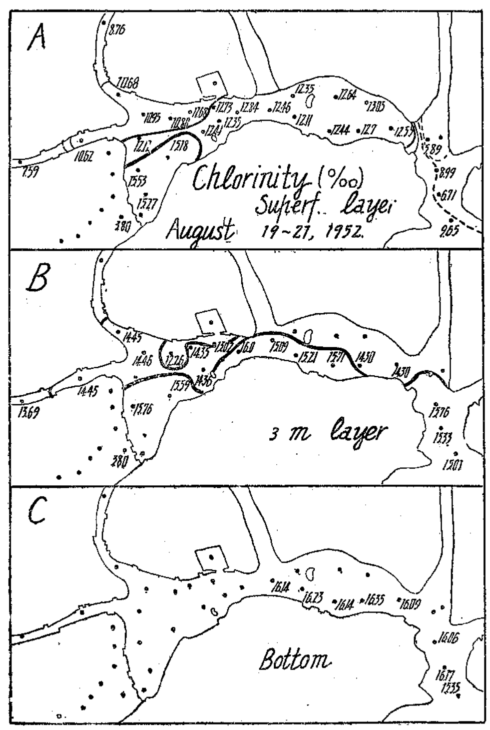


Fig. 9. Distribution of chlorinity in ‰ during August 19–21, 1952.

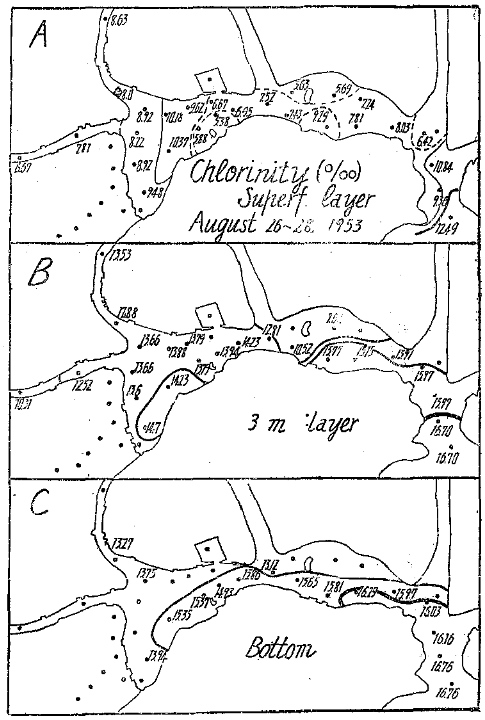


Fig. 10. Distribution of chlorinity in ‰ during August 26–28, 1953.

is uniformly muddy (Fig. 2, B). The bay is poured by four large rivers, the Kurasiki, Sasagase, Asahi and Yosii. Mr. MAÉDA, one of our co-workers, observed the hydrological influences of these rivers on any region of the bay and stochastically analysed (MAÉDA, H. Publ. Seto Mar. Biol. Lab., II (2), p. 249, 1952).

For convenience' sake, the bay water may be treated separately into the surface (bay water with rich freshwater) and bottom waters (with rich Inland Sea water), although it is difficult to give definitely the boundary between them.

Water temperature (Figs. 3–6) : Generally speaking, the stratification of temperature is distinctly defined in observations made during May 31– June 1, 1951. The lowest temperature (7.0°C) recorded is during February 26–27, 1952, and the highest (29.7°C) at the surface during August 19–21, 1952. During May 31–June 1, 1951, the surface water was warmer than the lower water. The temperature increased towards both inner and outer shallower layers. In midsummer the water temperature is almost similar from surface to bottom. Further details are shown in Figs. 3 to 6.

Chlorinity (Figs. 7–11) : Chlorinity is the most satisfactory hydrological property for indicating the extent of mixing between the sea and freshwater, and its distribution is important in determination of the gradient of the sea water. And from the biological

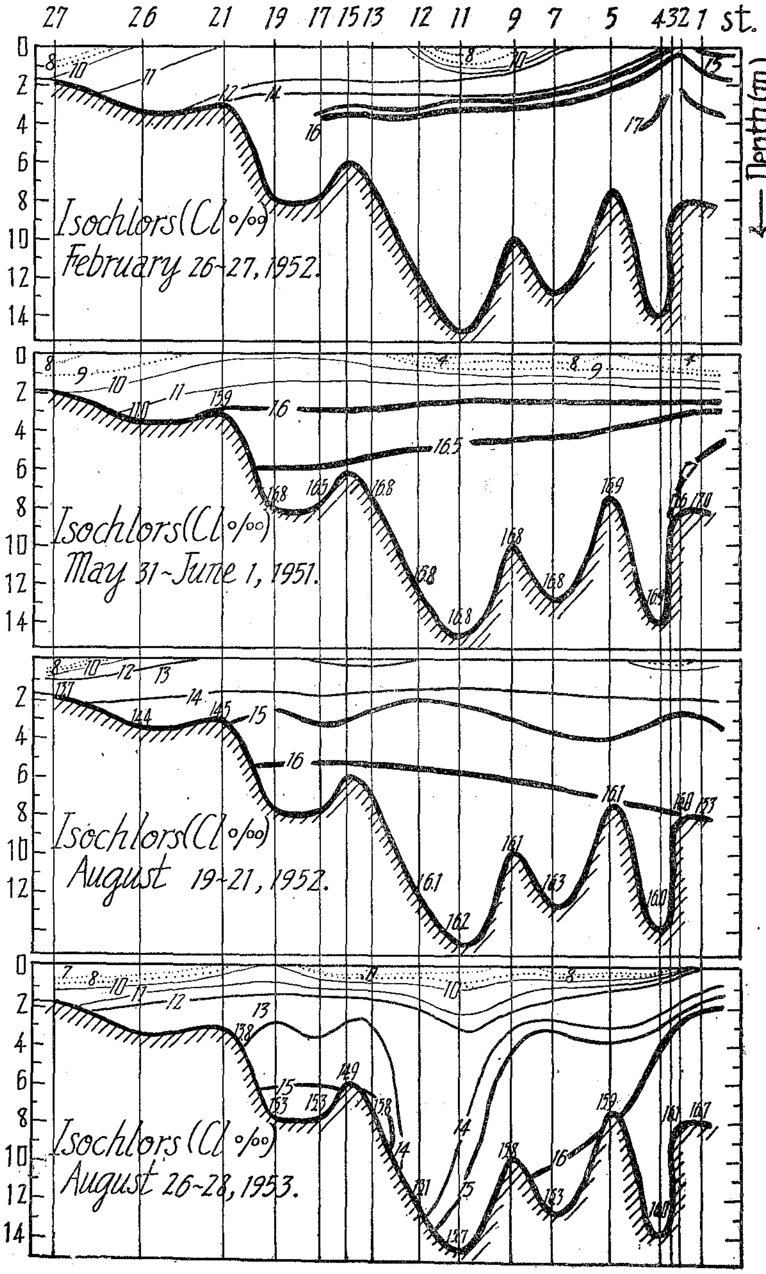


Fig. 11.
Variation of chlorinity in longitudinal section of the bay in different seasons.

standpoint the chlorinity distribution is a main factor in determining the distribution of marine, brackish and freshwater organisms.

In the shallow tide-influenced inner and northern basin of the bay, the chlorinity is generally low, even towards the bottom. In the deep layer from the mouth to the area along the southern coast, the water is comparatively more saline than elsewhere. The minimum chlorinity was observed in February 26–27, 1952 and the maximum in August 26–28, 1953, corresponding to the seasonal variation in river drainage. The vertical gradients at the mouth and the area along the southern coast extending from Sts. 5 to 19 were small except in the surface layer (Fig. 11). These subsurface water in the areas shows the characteristics of Inland Sea water.

Silicates (SiO_2) (Figs. 12, A–C and 13): The silicates of the bay were generally large. The seasonal change was large both horizontally and vertically. The maximum was observed at the surface during August 26–28, 1953, as large amounts of silicates were discharged from the four rivers. The silicates were generally maximum in less

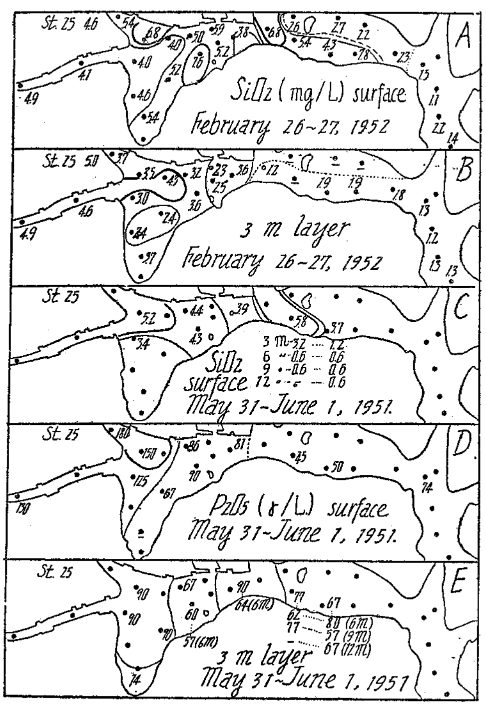


Fig. 12. Distribution of silicates (SiO_2 mg/L) and phosphates (P_2O_5 γ/L). (Above)

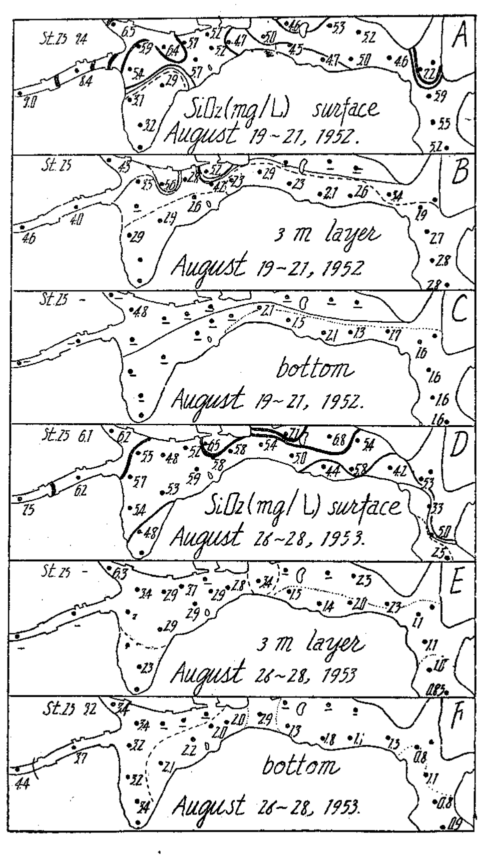
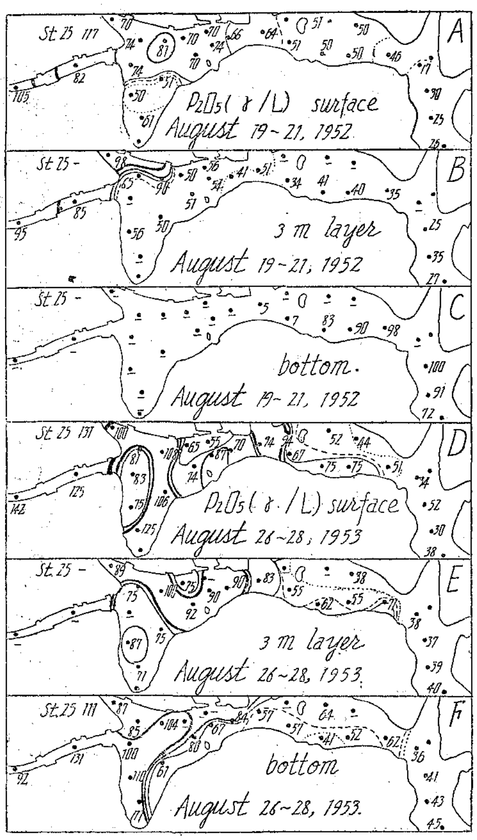


Fig. 13. Distribution of silicates (SiO_2 mg/L). (Right)

saline water in the shallower inner area and minimum in the highly saline water entering from the mouth of the bay.

Phosphates (P_2O_5) (Figs. 12, D, E and 14): The phosphates (P_2O_5) were largest in the inner region with 80–180 mg per cubic meter, and in the middle region with 60–80 mg per m^3, as observed during May 31–June 1, 1951. During August 26–28, 1953, it was also higher in the inner region of the bay than in the middle and outer regions. The lower phosphates were found in the deeper water of the middle region and the mouth. It may be seen that the higher values are characteristic to the estuarine water containing the sewage and polluted land water. The phosphates in this bay were probably derived from bacterial decomposition of organic phosphorus compounds pouring out of sewage.

Transparency (Fig. 15): The transparency of the water was very small at all stations, measuring only about 0.5–2.0 meters. It was smallest in the inner region



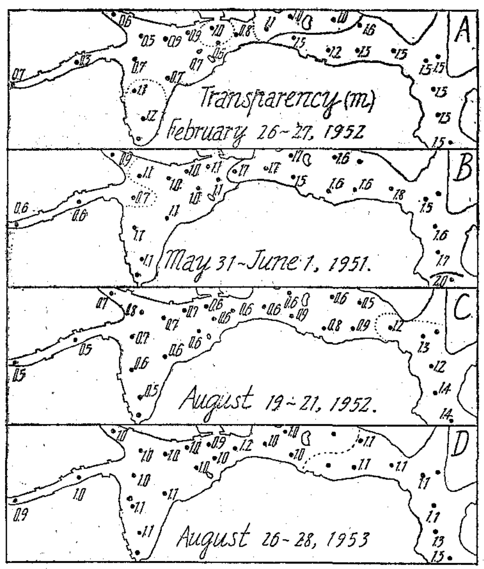


Fig. 15. Distribution of transparency in meter. (Above)

Fig. 14. Distribution of phosphates (P_2O_5) in γ per liter. (Left)

polluted strongly by the water pouring out from the rivers and ponds. It was only slightly higher than 1.5 meters even at the mouth.

Dissolved oxygen (Fig. 16): The dissolved oxygen content was smallest in August in the innermost region especially at the mouth of the Kurasiki. It increased towards the entrance of the bay. It was generally high at all stations during February 26–27, 1952.

Hydrogen-ion concentration (Fig. 17): The distribution of the hydrogen-ion concentration of this bay corresponds closely with that for dissolved oxygen, with high values in the mouth and the deep layer along the southern coast decreasing towards the inner region and estuaries. In the deeper water, low pH values were generally associated with the dissolved oxygen minima especially in summer. The drop in pH value during August 26–28, 1953 is probably due to the increase of carbon dioxide in the water.

Catalytic activity of sea water (Figs. 18 and 19): The catalytic activity of sea water was generally low. The highest value was found in the deeper water where the Inland Sea water stretched along the bottom.

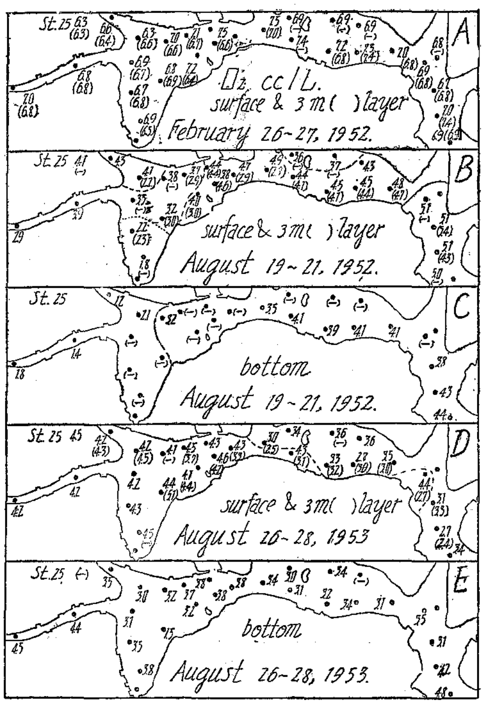


Fig. 16. Distribution of dissolved oxygen concentration in cc per liter.

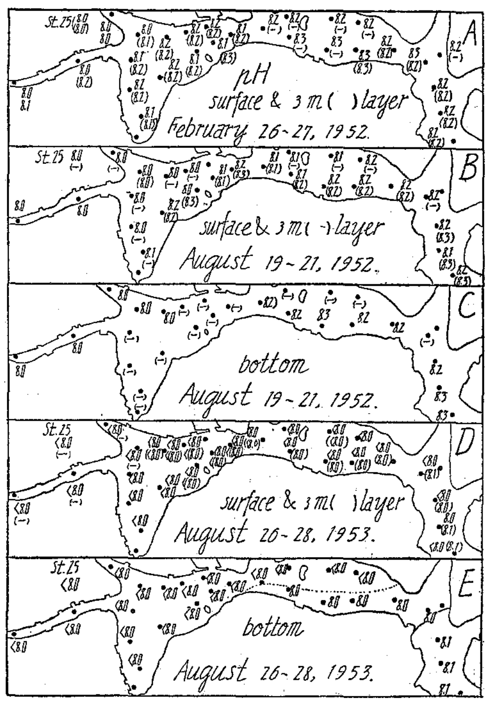


Fig. 17. Distribution of hydrogen-ion concentration (pH).

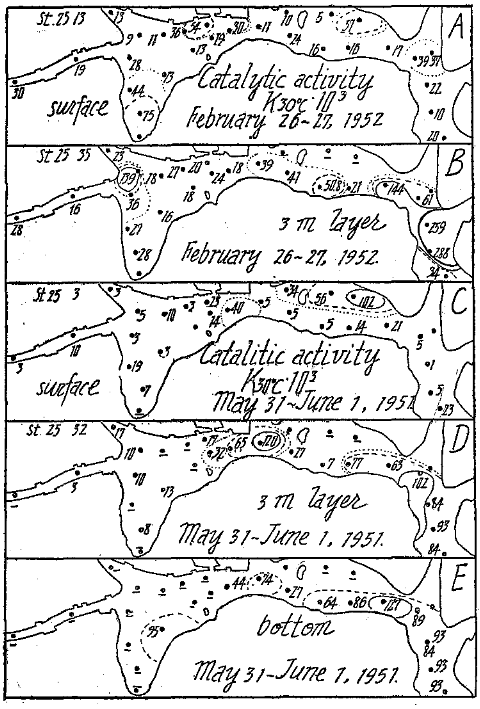


Fig. 18. Distribution of catalytic activity of sea water in $K_{30°C} \cdot 10^3$.
A and B. During February 26–27, 1952.
C, D and E. During May 31–June 1, 1951.

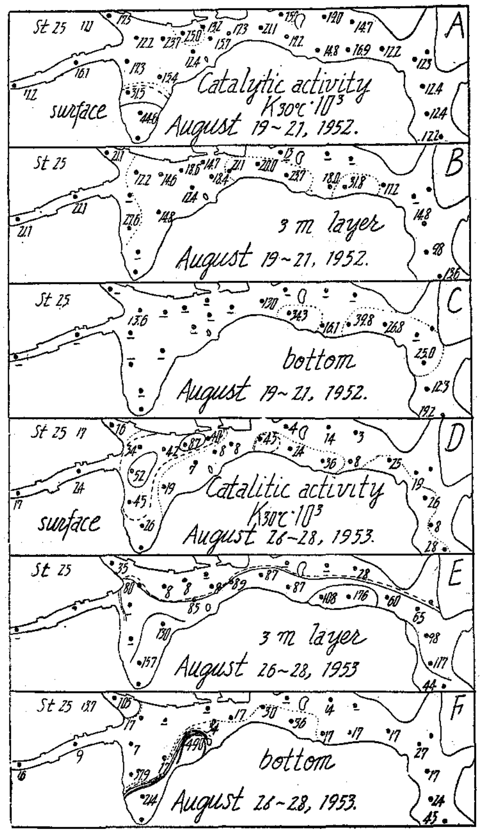


Fig. 19. Distribution of catalytic activity of sea water in $K_{30°C} \cdot 10^3$.
A, B and C. During August 19–21, 1952.
D, E and F. During August 26–28, 1953.

Plankton

A. Quantitative Analysis of Plankton

The total number of plankton was very small in every time of observations and also throughout all stations. The largest number was found at the mouth of the bay, in hauls made during August 19–21, 1952 (Figs. 20 and 21).

The relation between the settling volume and the total number of individuals, cells or colonies of total plankton caught during these surveys from the 3 m layer to the surface are shown graphically in Fig. 22. Both are nearly closely related to each other in the middle and inner regions of the bay in every season, but not so towards the mouth.

Total number per one meter haul increased considerably towards the mouth more than the volume did. In the middle and inner regions, the volume was likewise large, but the number decreased less than that in the mouth. This is due to the different components of plankton, especially the increase in number of copepods and the decrease of phytoplankton in the inner region of the bay. Throughout all stations they were greatest in August and medium in February.

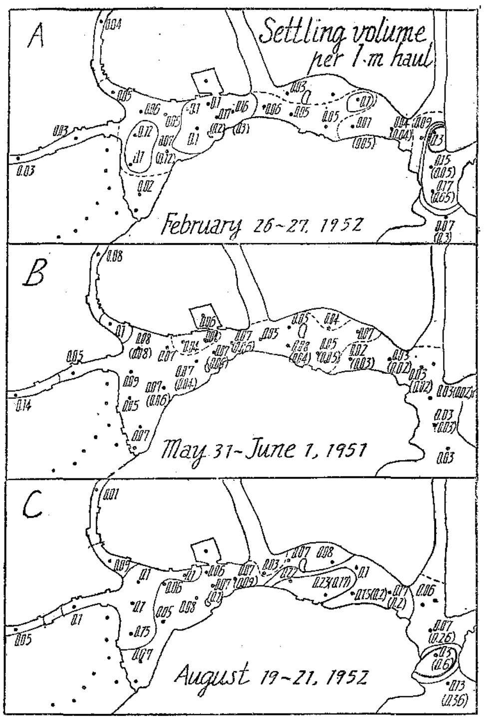


Fig. 20. Settling volume (cc) of plankton per one meter haul from the 3 meter layer to the surface.

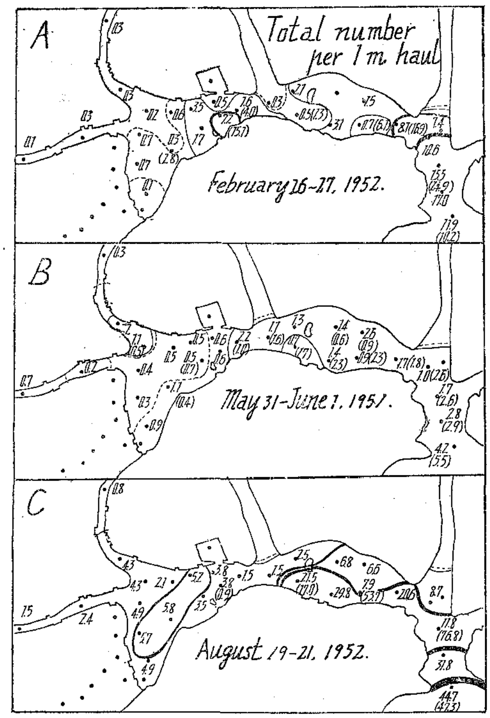


Fig. 21. Distribution of total number of plankton (individuals, cells or colonies) per one meter haul from the 3 meter layer to the suface (Unit of number is thousand).

The zooplankton was found densest in the inner region, where the number reached 1,000–5,000 per one meter haul during August and followed by 300–1,000 during May–June. The population of zooplankton was generally richest in the inner region and the neighboring rivers. The phytoplankton was whenever very scarce throughout all stations. It was, however, fairly richer in the mouth and the area along the southern coast of the middle region than in the innermost region.

The numerical percentage of zooplankton in total plankton was very large in the inner region of the bay, where it reached more than 90%, next in the middle, varying from 30 to 80% (Fig. 23). It was smallest in the mouth, particularly during February 26, 1952. On the other hand the percentage of phytoplankton was very scarce whenever. Relatively dense population of phytoplankton was found solely along the southern coast of the middle region from the mouth.

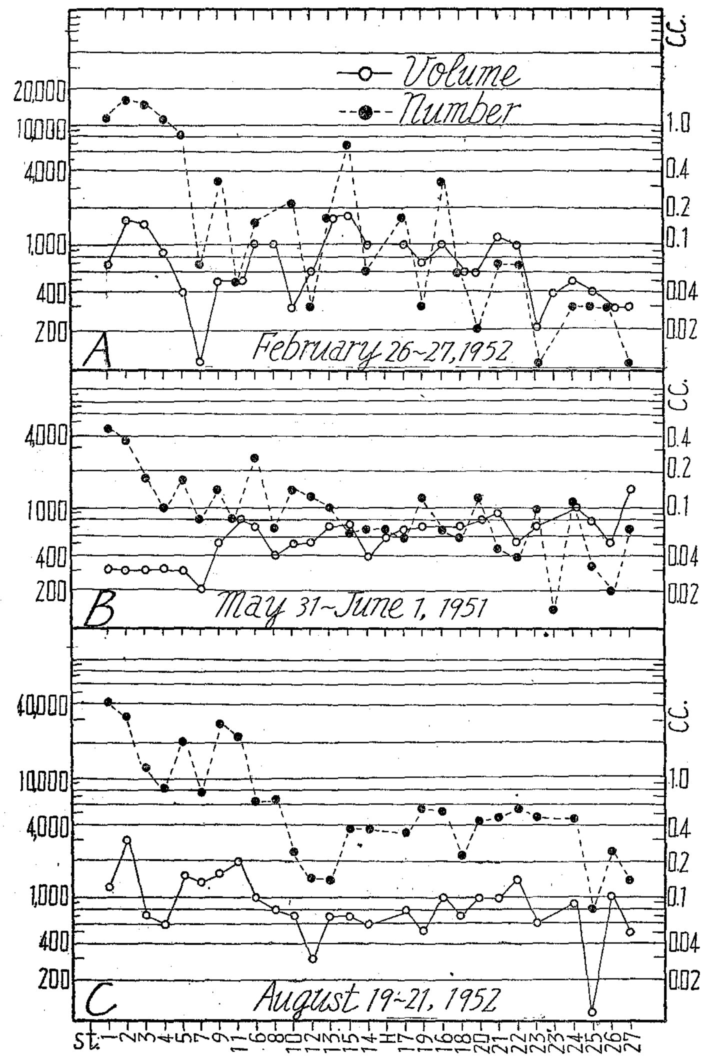


Fig. 22. Relation between settling volume (cc) and number of individuals, cells or colonies per one meter haul.

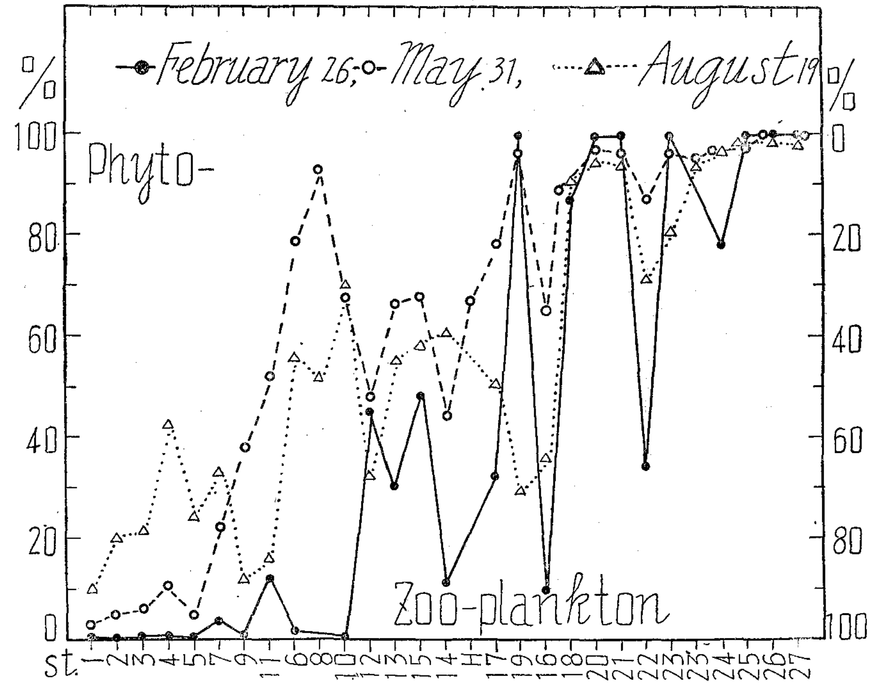


Fig. 23. Percentage composition between total number of zoo- and phytoplankton per one meter haul.

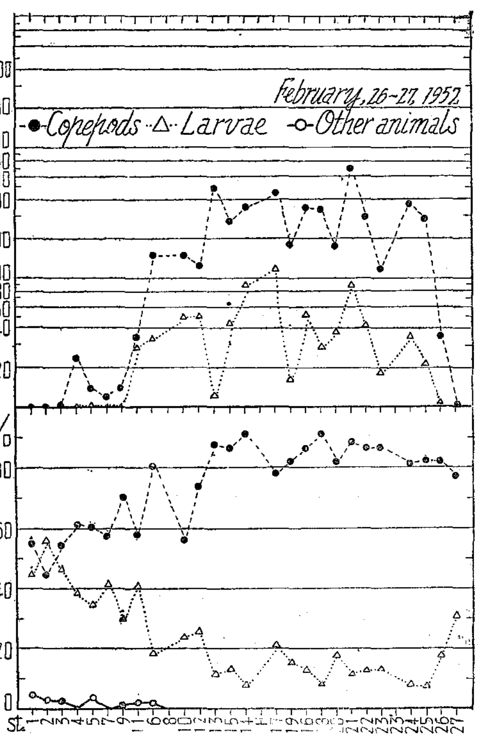


Fig. 24. Population of zooplankton groups per one meter haul (top), and their percentage composition (bottom) during February 26-27, 1952.

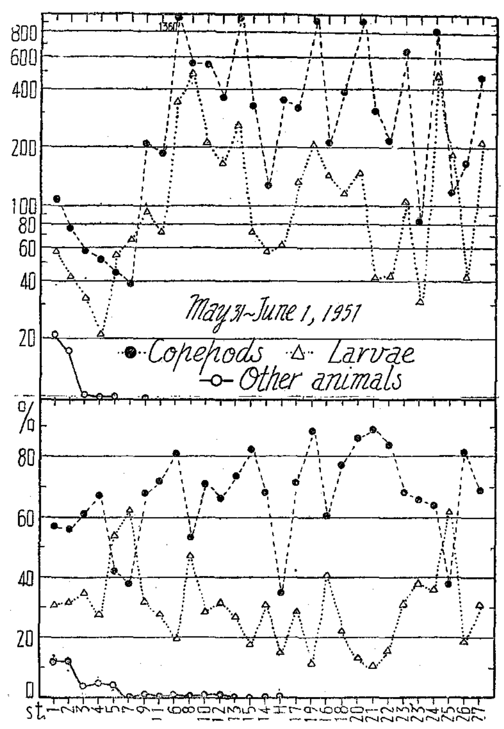


Fig. 25. Population of zooplankton groups per one meter haul (top), and their percentage composition (bottom) during May 31-June 1, 1951.

B. Qualitative Analysis of Plankton

ZOOPLANKTON

The occurrence and maxima of the main zooplankton groups are summarized in Figs. 24, 25 and 26. It is clear that they are characterized not only by the local abundance of the main components but also by their composition. The main group was as usual copepods at anytime, and followed by larval forms. The other animals were very poor throughout all stations. The smallest number was encountered during February 26–27, 1952, although observed a small number of copepods and larval forms.

The copepods as well as the larval forms were relatively numerous towards the inner region. The population of copepeds was greater during May 31–June 1, 1951 than during February 26–27, 1952. The larval forms of copepods also occurred abundantly. During August 19–21, 1952, the bulk of large population of copepods and

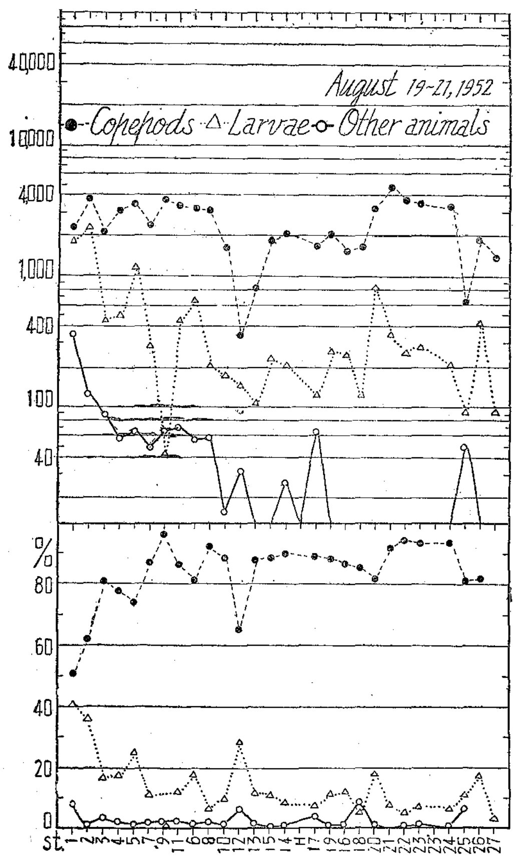


Fig. 26. Population of zooplankton groups per one meter haul(top), and their percentage composition (bottom) during August, 1952.

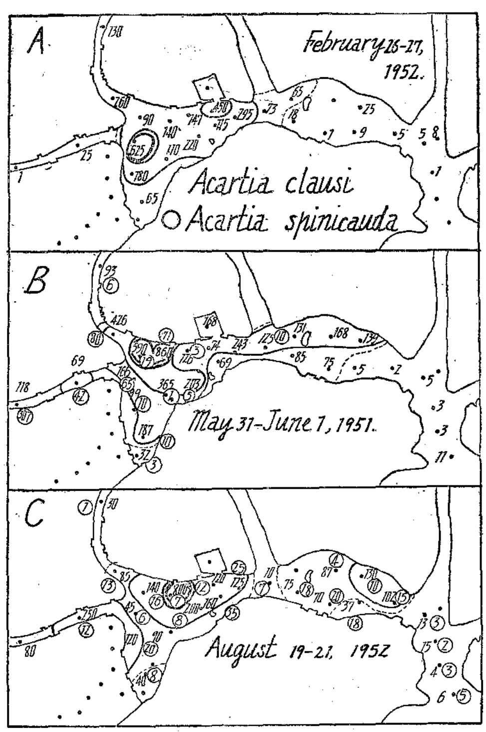


Fig. 27. Distribution of *Acartia clausi* and *A. spinicauda* showing the seasonal variation in occurrence.

their larval forms were noticed at all stations. The other animal groups only found in the mouth and the southern part of the middle region except during August were considerably scarce.

The following copepods were found dominantly: 1) *Sinocalanus tenellus,* 2) *Pseudodiaptomus inopsis,* 3) *Acartia clausi,* 4) *Acartia spinicauda,* 5) *Oithona nana,* 6) *Paracalanus parvus,* 7) *Euterpe acutifrons,* 8) *Centropages* sp. 9) *Oithona similis,* 10) *Microsetella rosea,* 11) *Corycaeus crassiusculus.*

Figs. 27–29 show the distribution of four predominant copepods with numerical abundance. During February 26–27, 1952, there was found a few species and the total population was relatively small. *Acartia clausi* was the most numerous component especially in the inner part of the bay. *Oithona nana* was relatively rich in the northern part of the inner region, but very poor towards the middle and mouth region. The real brackish water forms, such as *Sinocalanus tenellus* and *Pseudodiaptomus inopsis,* were recorded only sporadically in the innermost part and estuaries of the Kurasiki and Sasagase. *Paracalanus parvus, Oithona similis* and small numbers of *Microsetella rosea* and *Corycaeus crassiusculus* occurred only in the mouth region of the bay.

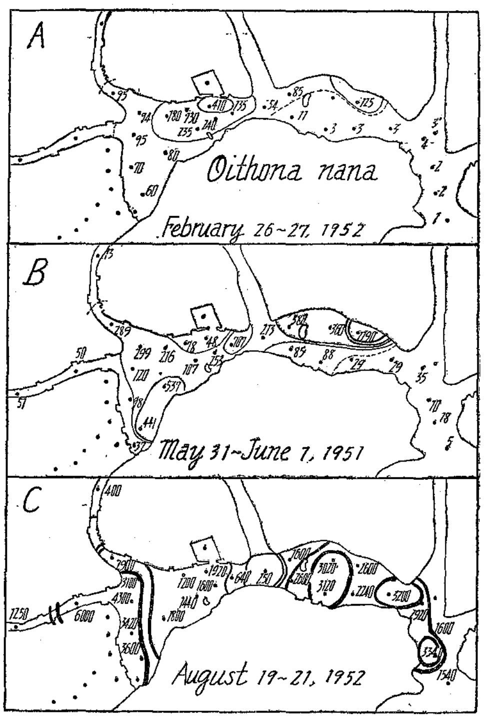


Fig. 28. Distribution of *Oithona nana* showing the seasonal variation in occurrence.

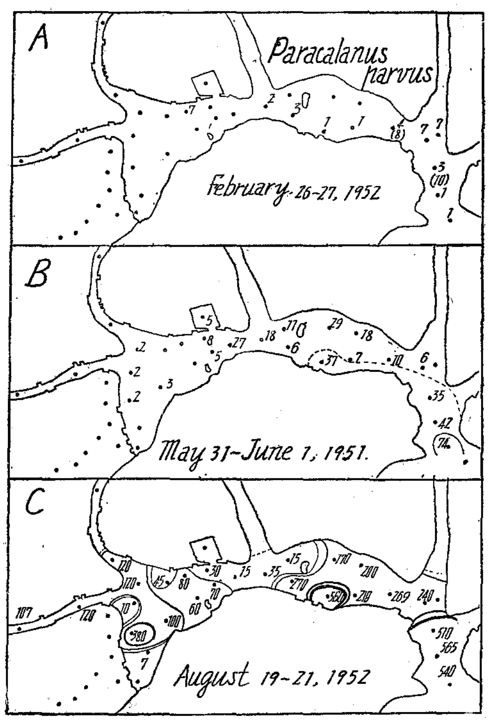


Fig. 29. Distribution of *Paracalanus parvus* showing the seasonal variation in occurrence.

During May 31–June 1, 1951, these species remarkably increased, and in addition *Acartia spinicauda* appeared for the first time in the inner region of the bay, particularly near the estuaries (Fig. 27, B). The other copepods showed the similar distribution as before.

During August 19–21, 1952, all these copepod populations enormously increased and probably reached their maximum; *Oithona nana* and *Paracalanus parvus* were rather widely distributed, while *Acartia clausi*, *Acartia spinicauda*, together with *Sinocalanus tenellus* and *Pseudodiaptomus inopsis* were rather restricted to the inner regions, and *Microsetella rosea*, *Corycaeus* and *Oithona similis* were only found sparsely mouth of the bay.

The percentage composition of these main copepods in different seasons is summarized graphically in Figs. 30, 31 and 32. In the inner region of the bay, *Acartia spinicauda* was the most abundant during early summer, though absent in winter. This is an inshore and brackish water form living in waters of relatively low salinities. In Jû-san Gata, KOKUBO and SATO (1947)[1] found it very commonly in low saline water with 2.49–16.15‰ Cl. *Acartia clausi*, on the other hand, is more widely distributed than *Acartia spinicauda* and can thrive in cold waters. It is found abundantly in every season, except in hot midsummer. *Oithona nana* was the most predominant in every season except in the innermost part during early summer and occurred very abundantly everywhere.

Besides copepods, *Podon* was often observed in August. A chaetognath *Sagitta crassa*, *S. crassa* f. *naikaiensis* and a tunicate *Oikopleura dioica* were found sparsely in the mouth of the bay in February and August, but rather abundant in May–June. A rotifer *Synchaeta* sp. occurred widely at all stations, though in small numbers. Among tintinnoids, *Tintinnopsis mortensenii*, *T. nordqvisti*, *T. radix*, *T. beroidea*, *Favella ehrenbergii* and *F. campanula* were frequent in the mouth to the southern coast of the middle region in August alone. *Noctiluca*, on the other hand, was found only in February.

The main components of larval forms were copepod nauplii. The larvae of polychaetes, veligers of pelecypods and gastropods, Ophiopluteus and nauplii of cirriped were small in abundance. Copepod nauplii which were mostly represented by *Oithona nana* and *Acartia* were frequent everywhere in all seasons. The larvae except copepod nauplii were generally restricted to the mouth and the southern area of the middle region.

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1) KOKUBO, S. and SATO, S. 1947. Plankters in Jû-san Gata. Physiology and Ecology, Vol. 1, No. 4, pp. 209–224.

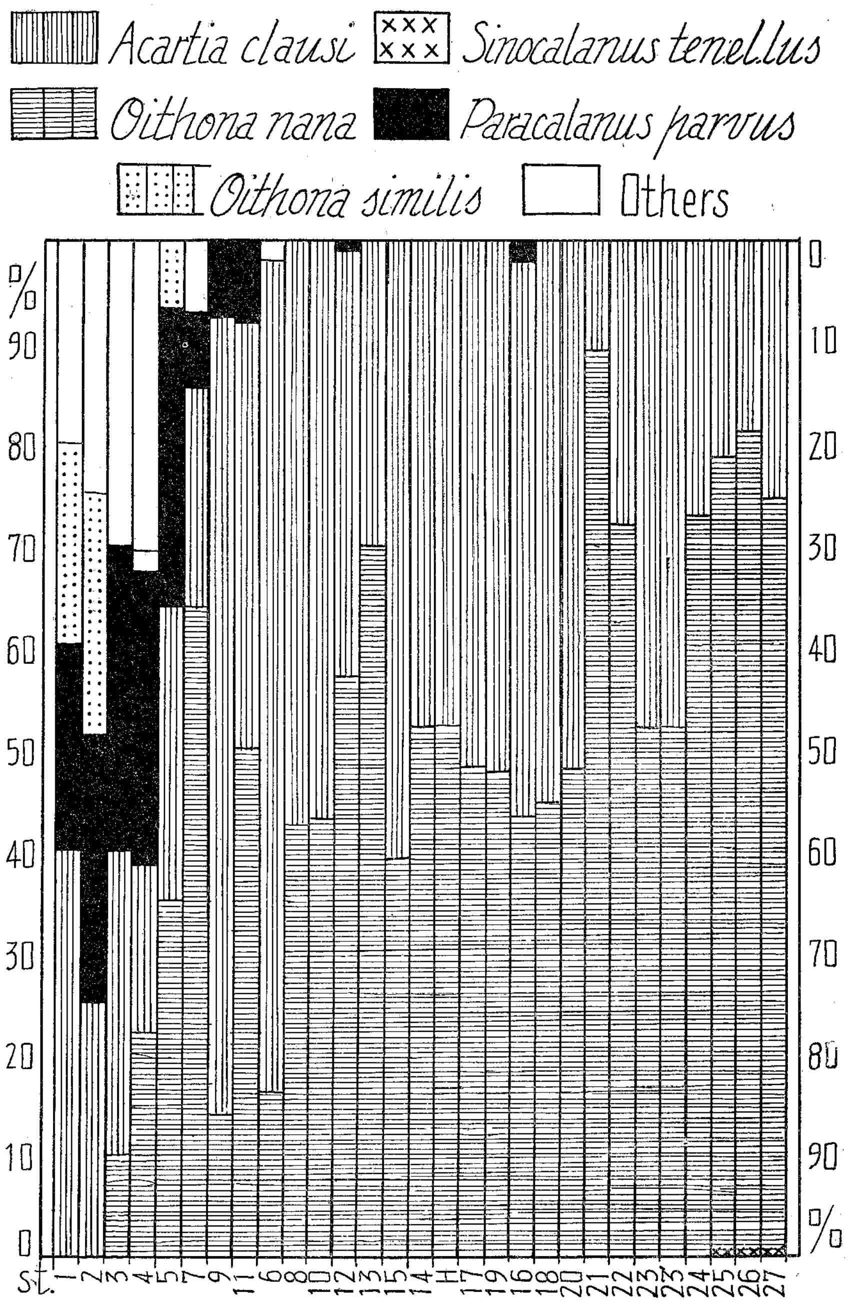

Fig. 30. Percentage composition of important copepods per one meter haul during February 26-27, 1952.

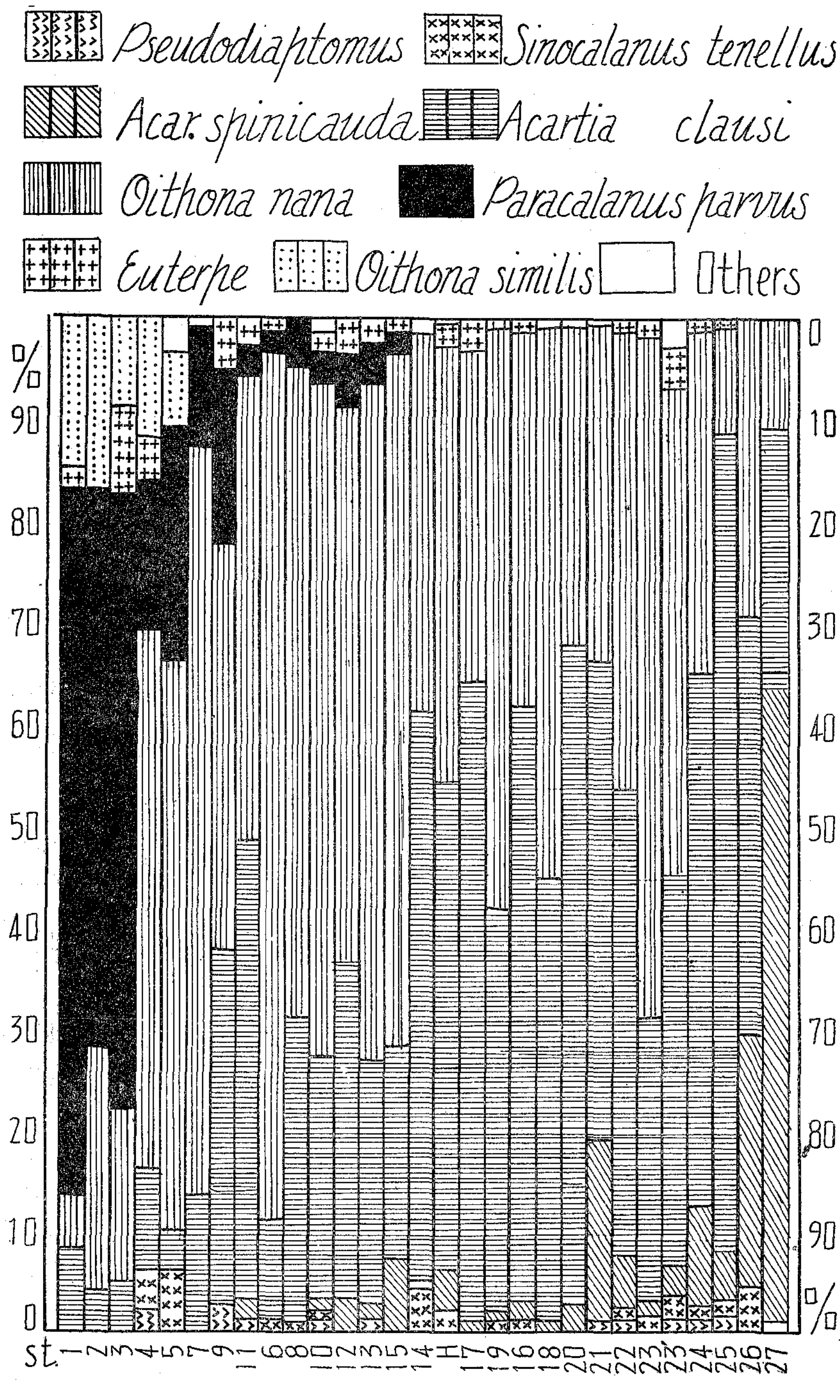

Fig. 31. Percentage composition of important copepods per one meter haul during May 31-June 1, 1951.

PHYTOPLANKTON

The population and composition of phytoplankton of this bay are characterized by, 1) the general paucity in occurrence, 2) the distribution limited to the southern part of the middle and mouth regions, and 3) the relatively small number of species except in summer.

Phytoplankton during February 26–27, 1952: The total number was very small, only less than 20 thousands as cells or colonies per one meter heul at the richest station near the mouth of the bay. The main component was diatoms, such as *Rhizosolenia setigera* (less than 7 thousands per one meter haul), *Rh. alata* forma *gracillima* (less than 0.3 thousands), *Asterionella japonica* (less than 4 thousands), *Chaetoceros* spp. (less than 7 thousands) and *Coscinodiscus* spp. (less then 1.5 thousands). The species occurred only in the mouth and the southern coast of the middle region. The other 33 species were found near the mouth, but they were very small in number. The dinoflagellates were very scanty, only *Ceratium fusus* and *Cer. intermedium* being found in the mouth.

Phytoplankton during May 31–June 1, 1951: The total number was smaller than in the preceding season, though showing the similar distribution. It was only less than 6 thousands per one meter haul at the richest station near the mouth. The important species was *Thalassiothrix Frauenfeldii*, *Biddulphia mobiliensis*, *Rhizosolenia calcar avis*, *Chaetoceros affinis* and *Chaetoceros decipiens*. The other 38 species of diatoms were restricted to the mouth very scantily. *Ceratium fusus* was only very sparsely found in the mouth.

Phytoplankton during August 19–21: The phytoplankton was dominated by diatoms in the mouth region alone. The main diatom species are *Thalassiothrix Frauenfeldii* (less than 5 thousands per one meter haul), *Coscinodiscus stellaris* (less than 16 thousands), *Chaetoceros* (less than 9 thousands), *Coscinodiscus granii* (less than 2 thousands), *Nitzschia seriata* (less than 1.5 thousands), *Rhizosolenia calcar avis*, *Rh. hebetata* f. *semispina* and *Rh. imbricata* (less than 0.4, 0.2 and 0.5 thousands, respectively). The other 29 diatoms were found in the mouth, but they were very sparse in number. Dinoflagellates were a little more numerous than during May 31–June 1, 1951, and represented only by *Ceratium fusus* (less than 90 per one meter haul), *Cer. tripos* (less than 70), *Peridinium depressum* and *Per. oceanicum* var. *oblongum* (less than 400) all of which occurred in the mouth.

These data suggest that they were introduced from the Inland Sea by the currents. It should be considered that at least in this bay the less saline and highly polluted waters do not permit to flourish for diatoms and dinoflagellates, although nutrient salts such as phosphates and silicates are very abundantly contained throughout the year. Generally, there was no direct correlation by grazing between zooplankton and phyto-

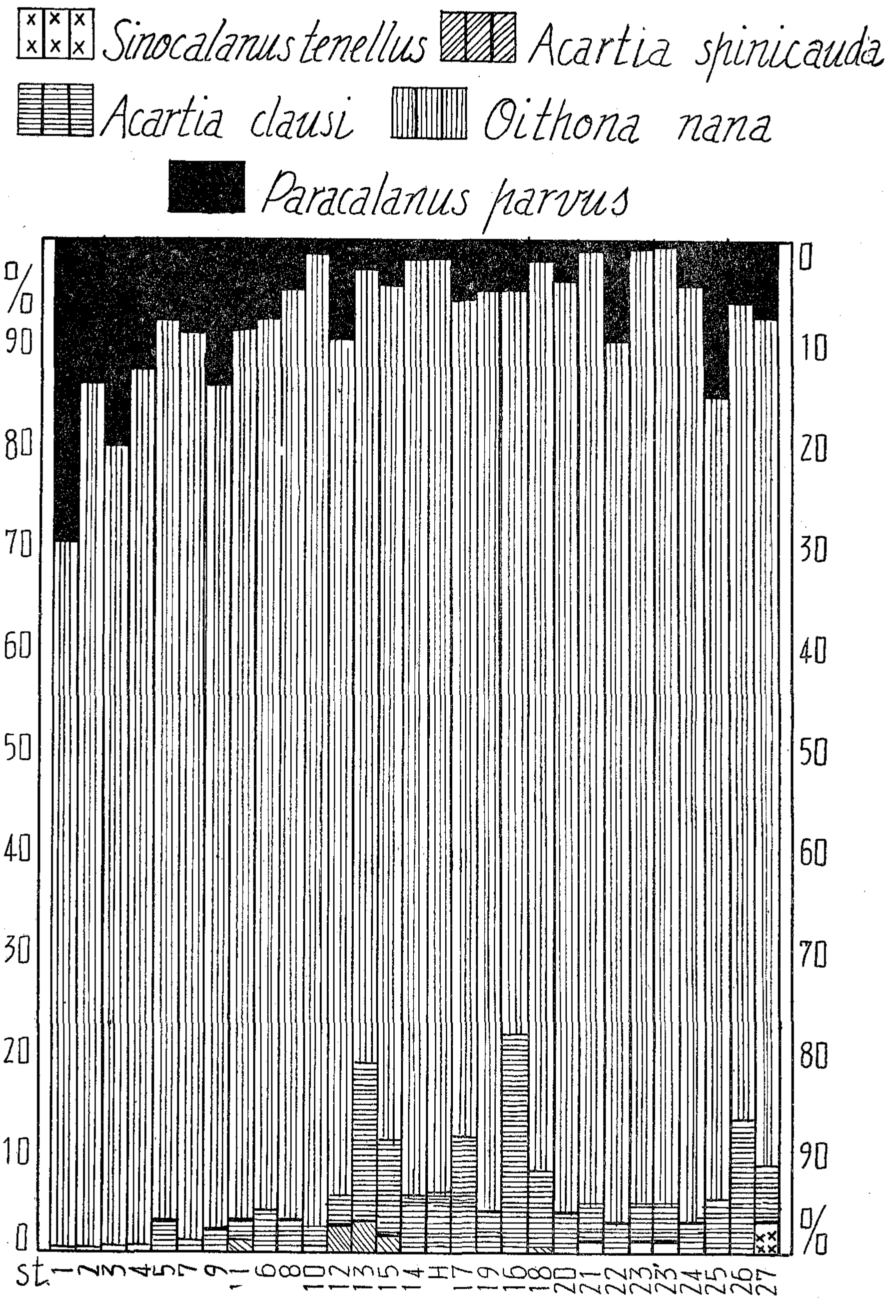

Fig. 32. Percentage composition of important copepods per one meter haul during August 19–21, 1952.

plankton. The zooplankton, especially copepods, were always abundant, while the phytoplankton less numerous at all stations.

Consideration on Regional Distribution

From the preceding data it is obvious that Kozima Bay possesses an estuarine environment, which is influenced by tide, but it is not the actual brackish water environment subject to dilutions by freshwater and rainwater and not influenced by tidal movement. The plankton in the bay seems to be rather monotonous in composition and uniform in abundance, but its distribution is correlated with the topographical and hydrological conditions. The distributions of the dominant copepods and its associates and their seasonal variations in Kozima Bay during the periods 1951–53 are summarized as follows (Fig. 33) :

1. *Acartia clausi* community.

A real inshore copepod *Acartia clausi*, which is fairly euryhaline and eurythermal, appears all the year round, but is comparatively abundant from winter to early summer. The main habitat is, however, rather confined to the narrow area of less saline waters of the innermost region. It is associated with *A. spinicauda* in summer and also with a large number of *Oithona nana* in all seasons. Other associates are brackish water copepods such as *Sinocalanus tenellus* and *Pseudodiaptomus inopsis* in early summer. The marine diatoms are not found at all within the area where this community keeps its predominance. Thereabout the water shows very low transparency, low catalytic activity and very low salinity.

2. *Oithona nana* community.

The whole area of the bay is densely occupied by a widespread inshore form *Oithona nana*. In is associated with *Acartia clausi* and *A. spinicauda* in the inner region and with *Paracalanus parvus* and *Oithona similis* in the outer region. Other associates in the outer region are *Oncaea* sp., *Oikopleura dioica*, *Sagitta crassa* f. *naikaiensis*, etc. In this community the following two faciations may be recognized.

(a) *Oithona nana—Acartia clausi* community.

In the inner area *Oithona nana* occurs with rich *Acartia clausi*. *Oithona nana* is the most dominant copepod of all zooplankton in this bay, widespread in all areas, and predominates especially in midsummer. In other seasons, it is also found abundantly in the wide area from the inner to the middle region, but associated with a large number of *Acartia clausi* and a small number of *Euterpe acutifrons*.

(b) *Oithona nana—Paracalanus parvus* community.

The mouth part of the bay is predominated by *Paracalanus parvus* and *Oithona nana* (together with *Oithona similis* except in midsummer). The occurrence of

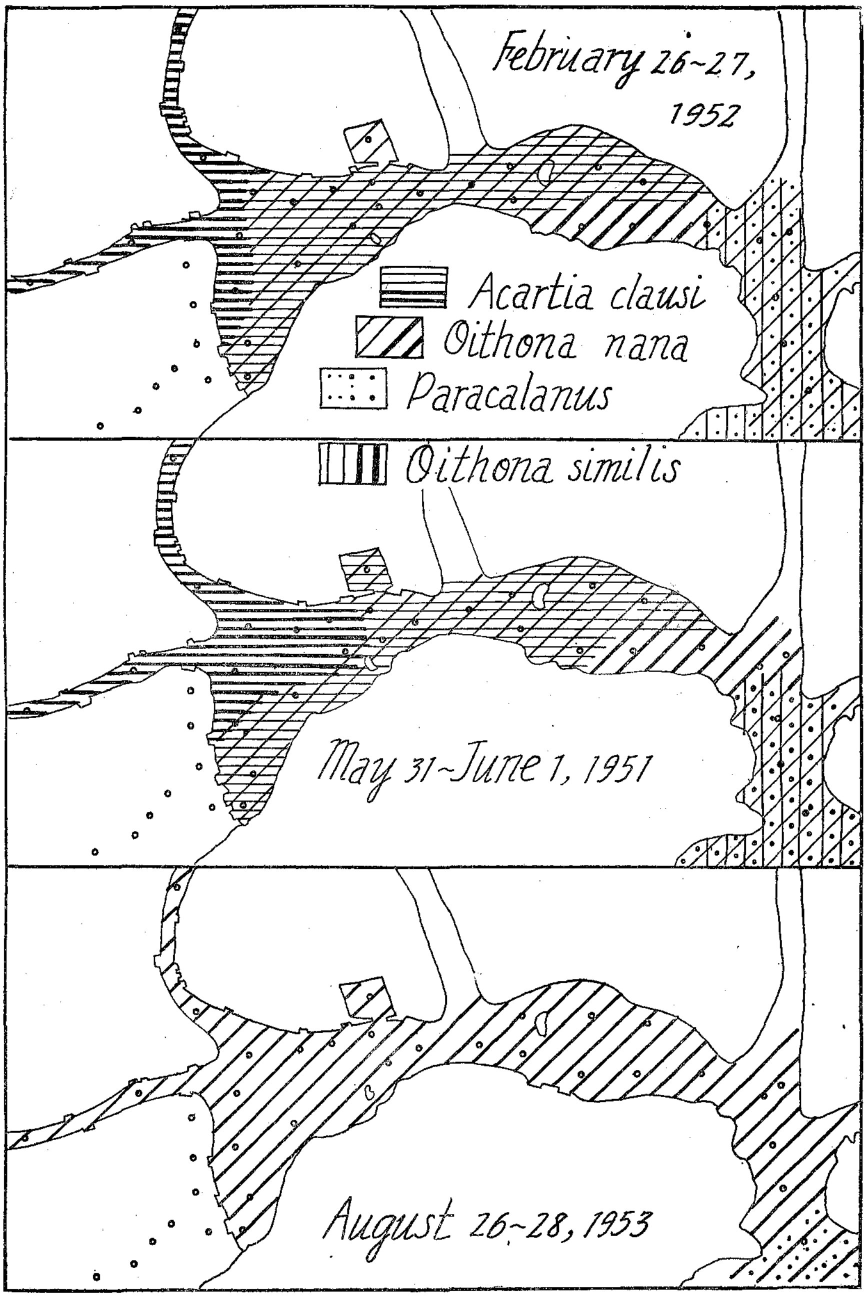

Fig. 33. Distributional map of dominant copepods in Kozima Bay during the periods of February 26–27, 1952 (top), May 31–June 1, 1951 (middle) and August 26–28, 1953 (bottom).

Paracalanus parvus is confined chiefly to the mouth region during the period from winter to early summer, although this area penetrates considerably into the head of the bay in the following summer as revealed by the survey during August 19–21, 1952, when the hydrological conditions of this area were similar to those of the Inland Sea outside the bay, the variations of chlorinity and temperature being relatively smaller than in the inner area of the bay occupied by the preceding communities. The phytoplankton, especially diatoms, is rich around the entrance of the bay. It may therefore be concluded that the major phytoplankton components in this area may be carried in from the Inland Sea during the times when the tidal current is strong and, as a result, the water is turbulent.

In conclusion, the plankton of Kozima Bay is largely composed of the mixed communities of *Oithona nana* and *Acartia clausi.* The outer region is dominated by the former species, while the inner region by the latter. Both populations and almost all the other components are generally encountered all the year round, except only *Acartia spinicauda* found during the warm period. The seasonal variation in quantity is of course observed. The relationship between the numerical abundance of zooplankton and temperature is actually complicated. But in the case of a certain species the number of individuals generally increases with the rise of the water temperature. The productivities of diatoms and dinoflagellates are always very poor in contrast with the dominance of zooplankton. The number of species is also small.